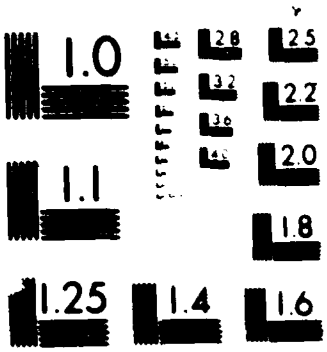
AD-A176 162 EYE MOVEMENTS AND VISUAL INFORMATION PROCESSING(U) 1/1
RUTGERS - THE STATE UNIV NEW BRUNSWICK N J DEPT OF
PSYCHOLOGY E KOWLER 09 MAY 86 AFOSR-TR-86-0513
UNCLASSIFIED AFOSR-84-0085 F/G 6/16 NL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REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 86-0513
6a NAME OF PERFORMING ORGANIZATION Rutgers -The State University; 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Air Force Office of Scientific Research/NL
6c ADDRESS (City, State, and ZIP Code) Department of Psychology New Brunswick NJ 08903	7b ADDRESS (City, State, and ZIP Code) Building 410 Bolling AFB, DC 20332-6448
8a NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR; 8b OFFICE SYMBOL (If applicable) NL	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-84-0085
8c ADDRESS (City, State, and ZIP Code) Building 410 Bolling AFB, DC 20332-6448	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO 61102F; PROJECT NO 2313; TASK NO A5; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

EYE MOVEMENTS AND VISUAL INFORMATION PROCESSING

12 PERSONAL AUTHOR(S) Dr Eileen Kowler

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final	FROM 81/1/01 TO ~~84/12/3~~ 84/06/30	86 May 09	8

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Completed studies showed that: (1) saccade-like stimulus transients (abrupt onsets or offsets) do not aid visual search (Kowler and Sperling, 1983); (2) anticipatory smooth eye movements depend in a lawful way on the stimuli in prior trials (Kowler, Martins and Pavel, 1984); (3) smooth pursuit eye movements are determined by two, independent processes (Martins, Kowler and Palmer, submitted ms); (4) reading efficiency is not limited by the pattern of eye movements, but rather by the ability to recognize words quickly (Kowler, Anton and Lopez, Psychonomics talk, ms in preparation); (5) subjects can maintain the line of sight on one of two, superimposed, full-field, patterns of randomly positioned dots -- one pattern moving and the other stationary.

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20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL JOHN F. TANGNEY	22b TELEPHONE (Include Area Code) (202) 767-5021; 22c OFFICE SYMBOL NL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED

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87 1 21 084

AFOSR-TR- 86-0513

ABSTRACT

Eye movements determine the location and velocity of the retinal image. Thus, to understand how we see it is necessary to understand both how eye movements are controlled and how they affect visual information processing. The proposed research is concerned with both problems. Specifically:

(1) The effect of expectations on smooth eye movements. The eye moves smoothly in the direction of expected future target motion. Experiments will determine: (1) how expectations and guesses about the direction of future motion are formulated and (2) the relative contributions of expectations and retinal image motion to smooth eye movements.

(2) The effect of saccades and saccade-like stimulus perturbations on visual information processing. Saccades continually displace the retinal image, yet we see the world as a single coherent picture. Experiments will find out whether the visual system selectively tolerates rapid lateral displacements, or whether the decision to move the eye is required.

(3) Programming sequences of saccades. Experiments will show whether sequences of saccades can be pre-programmed, and whether use of such sequences improvesperformance of visual tasks.

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PROGRESS REPORT (January 1, 1981 - June 30, 1984)

Development of laboratory facilities

The computer (LSI 11/23) arrived in spring, 1981. Computer programs were written to analyze eye movement and psychophysical data we collected elsewhere (Steinman's lab at the University of Maryland and Sperling's lab at New York University).

The SRI Generation IV Dual Purkinje Image eyetracker arrived in May, 1982. The tracker was tested and necessary adjustments made in collaboration with M. Pavel and C. Steele. The accuracy of the tracker was confirmed by: (1) recording motions of a calibrated artificial eye moving with known waveforms, and (2) comparing the eye movements of subjects performing simple tasks (e.g., fixation, step-tracking) to the eye movements previously recorded from these same individuals by means of other monitors (contact lens optical lever, Generation III tracker, scleral search coil monitor, revolving field monitor).

The noise level of the tracker was measured and is quite adequate for the planned experiments. Noise level, expressed as the standard deviation of position samples obtained from an artificial eye with: (1) intensities of the 1st and 4th image reflections set to values typical of human eyes, and (2) low pass filtering (50 Hz) and sampling rate (100 Hz) set to those values typically used in our experiments, was 0.4 min arc on the horizontal and 0.7 min arc on the vertical meridian.

Laboratory facilities necessary for the control of experiments were developed. This included: (1) construction and implementation of hardware interfaces (8-pole Bessel filters with 40 dB/oct attenuation, analog-to-digital converter) between the tracker and computer, (2) implementation of hardware interfaces (digital to analog converters) between the computer and CRT displays, and (3) development of software for the control of experiments and analysis of data.

Publications

Kowler, E. and Sperling, G. (1983). Abrupt onsets do not aid visual search. Perception and Psychophysics, 34, 307-313.

Kowler, E., Martins, A. J., and Pavel, M. (1984). The effect of expectations on slow oculomotor control--IV. Anticipatory smooth eye movements depend on prior target motions. Vision Research, 24, 197-210.

Submitted papers

Kowler, E., van der Steen, J., Tamminga, E. P., and Collewijn, H. Voluntary selection of the target for smooth eye movements in the presence of full-field stationary and moving stimuli. Submitted to Vision Research.

Martins, A. J., Kowler, E. and Palmer, C. Smooth pursuit of small amplitude sinusoidal motions. Submitted to the Journal of the Optical Society of America.

Talks

Kowler, E. Characteristics and visual consequences of saccades used to inspect displays. AFOSR Technical Group Meeting, May, 1982.

Kowler, E. and Sperling, G. The role of saccade-like stimulus transients in visual information processing. Association for Research in Vision and Ophthalmology, May, 1983.

Martins, A. J., Kowler, E. and Palmer, C. Contribution of slow control and smooth pursuit oculomotor subsystems to the tracking of sinusoidal motions. Optical Society of America, October, 1983.

Kowler, E., Anton, S. and Lopez, L. Reading reversed text. Psychonomic Society, November, 1983.

Kowler, E. and McKee, S. P. The precision of smooth pursuit. Association for Research in Vision and Opthalmology, May, 1984.

Kowler, E. Cognitive influences on smooth eye movements. AFOSR review, May, 1984.

Invited talk

Kowler, E. The role of voluntary selection in determining the input for smooth eye movements: Implications for psychophysical performance. To be given at Attention and Performance XI, Eugene, Oregon, July, 1984, and subsequently published in the conference proceedings.

Brief summary of completed experiments

Completed studies showed that: (1) saccade-like stimulus transients (abrupt onsets or offsets) do not aid visual search (Kowler and Sperling, 1983); (2) anticipatory smooth eye movements depend in a lawful way on the stimuli in prior trials (Kowler, Martins and Pavel, 1984); (3) smooth pursuit eye movements are determined by two, independent processes (Martins, Kowler and Palmer, submitted ms); (4) reading efficiency is not limited by the pattern of eye movements, but rather by the ability to recognize words quickly (Kowler, Anton and Lopez, Psychonomics talk, ms in preparation); (5) subjects can maintain the line of sight on one of two, superimposed, full-field, patterns of randomly positioned dots -- one pattern moving and the other stationary -- with no influence of the background, showing that voluntary selective attention can be completely effective in determining the input to the smooth oculomotor subsystem (Kowler, van der Steen, Tamminga and Collewijn, submitted ms); (6) the sensitivity of smooth pursuit to small changes in stimulus velocity is comparable to the sensitivity of psychophysical observers to these changes, suggesting common underlying mechanisms (Kowler and McKee, ARVO talk, ms in preparation).

Detailed summary of completed experiments

(1) Abrupt onsets (Kowler and Sperling, 1983). Performance on a visual search task was measured for displays containing an abrupt and a gradual (ramp) onset in order to test the hypothesis (Sperling et al., 1971) that abrupt

onsets initiate a brief period of information acquisition. The type of onset did not affect performance. Performance was the same for displays containing (1) an abrupt onset and gradual offset; (2) a gradual onset and abrupt offset; and (3) an abrupt onset and abrupt offset. These results extended earlier observations that imposing abrupt onsets and rapid, lateral displacements on visual displays do not affect visual search (Kowler and Sperling, 1980). Failure of onsets to affect visual search suggests that saccades need not be made solely to create retinal image transients. Saccades need to be made only to bring selected targets to the fovea (ms appended).

(2) Effect of expectations on smooth eye movement (Kowler, Martins and Pavel, 1984). This experiment showed that effects of expectations on smooth eye movement depended in a lawful way on the history of prior target motions. Anticipatory smooth eye movements (involuntary drifts in the direction of future target motion) were measured while subjects fixated a stationary target that was expected to step in an unpredictable direction (right or left). Anticipatory smooth eye movement velocity depended on the sequence of steps in prior trials, e.g., velocity was faster to the right when the prior steps were to the right. The influence of prior steps diminished the further back into the past the step occurred. Anticipatory smooth eye movement velocity was predicted by a two-state Markov model developed by Falmagne et al. (1975) for similar sequential dependencies observed in a manual reaction-time task (button-pressing). The model uses the prior sequence of target motions to predict the subject's expectation, and assumes that the expectation determines anticipatory smooth eye movement velocity. The fit of the model to the data was good, which showed that taking expectations into account allows accurate predictions about smooth eye movement velocity when target motions are unpredictable (ms appended).

(3) Smooth pursuit of small amplitude sinusoidal motions (

and Palmer, 1984). Subjects used smooth eye movements to track sm (1.9' to 30') sinusoidal motions with frequencies from 0.05 to 5.0 H. pursuit was evident (i.e., mean eye speed during smooth pursuit was gr than mean eye speed during slow control) at all stimulus frequencies betw 0.1 Hz and 3 Hz and at all stimulus amplitudes greater than 1.9'. Smooth pursuit, however, was generally poor. Mean retinal image speeds were low on. for target frequencies less than 1 Hz. Also, smooth pursuit gain (mean eye speed/mean stimulus speed) decreased as target frequency increased and as target amplitude increased.

Two surprising characteristics of smooth pursuit were observed. First, the dependence of smooth pursuit gain on target amplitude could be eliminated by subtracting a constant, from mean eye speed before computing gain. This result showed that smooth eye movements are determined by two independent processes, one which contributes a constant eye speed and the other which responds linearly to stimulus speed. Second, pronounced systematic drifts were superimposed on the oscillations of the eye. These drifts occurred at all but the highest frequencies and smallest amplitudes of target motion. The drifts created large position errors (up to 2 deg) but position errors did not abolish the oscillations. These results showed that smooth eye movements do not correct position errors. Instead, they create position errors while continuing to reduce retinal slip (ms appended).

(4) Role of stereotyped saccadic habits in reading (Kowler, Anton and Lopez, 1983). Subjects read text which was transformed in a variety of ways in an attempt to determine the relative contributions of fixed, stereotyped saccadic habits and visual recognition to reading. Texts were short passages from Science in which the order of letters and words were either normal or changed in one of the following ways: (1) the order of letters in a line were

reversed (e.g., "Hello there" becomes "ereht olleH"), thus requirin to read from right to left; (2) the order of words in a line was reve the order of letters in a word was unchanged ("there Hello"), again req subjects to read from right to left; and (3) the order of letters in a wo reversed while the order of words in a line was unchanged ("olleH ereht") requiring subjects to read from left to right, and requiring subjects to make frequent changes in the direction of saccades. The orientation of letters was also varied in order to separate detrimental effects of altering the direction of saccades from detrimental effects of altering the visual appearance of words. Passages were read under the instruction to strive for total comprehension. Reading t[illegible] not affected by the direction in which lines were scanned, nor by the [illegible]eq irement to make frequent changes in thedirections of saccades (Figure 8). Reading time was slowed by drastic alterations in the visual appearance of words produced by changing the orientation of letters, or by changing the order of letters within a word (Figure 9). These alterations were detrimental regardless of the directions of saccades. These results suggested that reading is limited by visual or memorial processes involved in the rapid recognition of words and not by fixed stereotyped saccadic habits.

(5) Voluntary selection of the target for smooth eye movements (Kowler, van der Steen, Tamminga and Collewijn, 1984). The effectiveness of voluntary selection in determining the target for smooth eye movement was determined by asking subjects to maintain their line of sight on one of two, identical, full-field, superimposed patterns of randomly-postioned dots. One field was stationary and the other moved at 70.2'/sec. The effect of the moving background on smooth eye movements when the stationary field was the target, and the effect of the stationary background on smooth eye movements when the moving field was the target was negligible (0% - 4% for one subject; 0% - 2%

for the other). These results showed that the effectiveness of volu selection in eliminating the influence of background stimuli on smooth movements can be virtually complete. Furthermore, any observed influenc the background -- however small -- could be attributed to voluntary facto (*e.g.*, subjects' failure to apply sufficient effort or attention) rather th to the operation of an involuntary mechanism that automatically integrated velocity information from target and background (ms appended).

(6) The precision of smooth pursuit (Kowler and McKee, 1984). Observers can reliably discriminate small (5%) differences in the velocity of moving targets (McKee, 1981). To find out whether the smooth pursuit subsystem demonstrates comparable precision, subjects tracked horizontal, constant velocity target motions. Velocity was randomly selected from a set of 5 velocities whose mean was either 0.5, 3.3 or 4.6 deg/s. The precision of the initial 500 msec of pursuit was poor (Figure 1), and eye velocity was influenced by the set of velocities presented in the session (Figure 2). Precise velocity discrimination was not observed 500 msec or more after motion-onset. Weber fractions ($\Delta v/v$) computed from eye velocities were comparable to those obtained psychophysically (Figure 3). These results suggested that the smooth pursuit subsystem uses the same velocity-sensitive mechanisms as the perceptual system, but processing of this information by the smooth pursuit subsystem is slower than expected from measurements of pursuit latency. Expectations of future target motion (Kowler and Steinman, 1979a,b, 1981) and memory for prior target motion (Kowler, Martins and Pavel, 1984) are the primary means by which large tracking errors are avoided during initial portions of smooth pursuit.

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